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ORIGINAL PAPER

The effects of environmental and non-environmental shocks on livelihoods and migration in Tanzania

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Abstract
Disruptive events and calamities can have major consequences for households in the predominantly agrarian communities of Eastern Africa. Here, we analyze the impacts of environmental and non-environmental shocks on migration in Tanzania using panel models and longitudinal data from the Tanzania National Panel Survey between 2008 and 2013. Shocks are defined as events that lead to losses in income, assets, or both. We find shocks resulting from changes in environmental conditions to be positively related to migration over time with more recent shocks exerting the strongest impact. According to our estimates, the probability of having a household member absent increases by 0.81% with each additional environmental shock encountered in the past 12 months. Different types of shocks have differential effects on migration with the strongest effects being observed for shocks with an immediate impact on household livelihoods, including through livestock losses and crop damage. Households in the sample are differently affected with rural, agriculturally dependent, and poor households without alternative income sources showing the strongest changes in their migration behavior in response to shocks. Our study adds important insights into the relationship between disruptive events and migration in Eastern Africa considering a broad time window and the compounding influence of different shock types. Our findings have a range of policy implications highlighting the need for a comprehensive perspective on household responses in times of distress that considers the interplay of different shock types as well as the role of context in shaping mobility patterns.

Keywords Migration · Climate change · Disasters · Poverty · Shocks · Tanzania

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Introduction

The persistent threat of shocks, especially due to environmental hazards, is a key risk to livelihoods in the largely agrarian countries of East Africa. Shocks are disruptive events that lead to a loss of household resources or livelihoods, a reduction in consumption, and/or a loss of productive assets (Dercon et al., 2005). To deal with the consequences of such events, households employ a variety of adaptation and coping strategies, from altering personal consumption patterns (Genoni, 2012; Hoffmann et al., 2022; Rosenzweig & Wolpin, 1993) to drawing on community-based risk sharing mechanisms (Choquette-Levy et al., 2021; Hoffmann, 2021).

Investing in the migration of a household member can also be a strategy to spread risks spatially and diversify household income sources, especially where local response options are limited (Katz & Stark, 1986; Lucas & Stark, 1985; Rosenzweig & Stark, 1989; Stark & Bloom, 1985). Many studies focusing on Sub-Saharan Africa have found that migration is used by households as a response to shocks such as illness and death of a family member (Lindstrom et al., 2022), major health issues and price decreases (Nikoloski et al., 2017), divorce (Reniers, 2003), breakup of the household (Anglewicz & Myroniuk, 2018), and health shocks such as HIV infections (Atake, 2018; Mtika, 2007).

Studies typically focus on estimating linear impacts of singular events on migration, considering long-term and long-distance, rural–urban or international movements (Beine & Parsons, 2017; Cattaneo & Peri, 2016; Codjoe et al., 2017; Feng et al., 2010; Gray & Mueller, 2012; Marchiori et al., 2012; Maystadt et al., 2016; Mueller et al., 2014). Few studies consider the impacts of environmental and non-environmental events jointly and how shocks interact in succession or in tandem with other types of shocks. This is even though shocks—including small-scale shocks—may occur frequently and depend on the previous occurrence of other shocks (Anglewicz & Myroniuk, 2018; Gray & Bilsborrow, 2013; Gray & Mueller, 2012). For example, environmentally induced shocks like pests contribute to health shocks that may themselves have implications for the mobility of the household (Sellers et al., 2019). There is some evidence that the effect of shocks on migration is additive; migration increases incrementally with each additional shock (Anglewicz & Myroniuk, 2018; Josephon & Shively, 2019; Lindstrom et al., 2022).

In this paper, we study the impact of different types of shocks over time on household migration in Tanzania. We rely on three waves of the Tanzania National Panel Survey (TZNPS), a nationally representative, georeferenced panel data set covering the period between 2008 and 2013 ($n = 3265$ households; 16,709 individuals). The data contain extensive information about social and economic characteristics as well as about 18 shocks reported by the households. We group the shocks into environmental and non-environmental shocks with the first category containing all shocks induced by changes in the natural environment, including extreme weather events and their impacts (Lenton, 2013, p. S61). Such environmental shocks can be highly damaging for agriculturally dependent livelihoods, and, because they affect a relatively large area and therefore many households, undermine the effectiveness of community response mechanisms (Bennett, 2015; Pradhan & Mukherjee, 2018). In contrast to environmental shocks, non-environmental shocks describe economic, social, political, or health-related disruptions. These are often idiosyncratic, such as illness in the family, but can also affect a community at large, such as increases in food prices (Kozel et al., 2008).

In our analysis, we consider both the aggregate impacts of environmental and non-environmental shocks as well as the impacts of the individual shock types using fixed effects panel models. Complementing previous studies, we consider a broad time window and shocks that have occurred in the recent and more distant past. The impacts of single shocks are thus not considered in isolation but against the background of the wider context of other shocks that have affected the household in different time periods 12 to 60 months prior to the survey. We contend that the temporal dimension plays an important role in understanding the dynamic and often non-linear nature of household responses to disruptive events (McLeman, 2018). Further disaggregating households by a number of fundamental characteristics such as wealth levels, location, agricultural dependency, and household composition, we explore differences across contexts to understand who is likely to migrate in response to shocks and under which conditions. Given that the frequency and intensity of environmental shocks are likely to increase with anthropogenic climate change, our paper adds important empirical grounding to contemporary debates on climate-related migration and has implications for policy discussions on climate adaptation, resilience, and issues surrounding loss and damage like critical thresholds.

The remainder of the paper is structured as follows: the "Theoretical considerations and previous literature" section discusses prior literature and theoretical frameworks for climate-related migration that informed this study; the "Data and methods" section provides background information on the Tanzanian context and introduces the main data source and methods used; the "Results" section presents the findings on the migration impact and interplay of environmental and non-environmental shocks, and the "Discussion and conclusion" section discusses the findings and concludes with ideas for future research.

Theoretical considerations and previous literature

A vast body of literature considers migration in the context of environmental changes and events, which are expected to become more frequent and intense with climate change (Clement et al., 2021; Foresight, 2011; Intergovernmental Panel on Climate Change (IPCC), 2013). The theoretical underpinnings of this literature are contested, and the causal chain through which migration occurs is an ongoing debate. A primary mechanism considered is through climate variability and extremes, as these most directly affect the agrarian household economy. Some scholars point to migration as a household insurance or risk reduction strategy in response to environmental or climatic risks (Angelucci, 2015; Bennett, 2015; Chegere & Mrosso, 2022; de Leon & Pittock, 2016; De Weerdt & Hirvonen, 2016; McLeman et al., 2021), as migration reduces resource pressure in origin areas and diversifies household livelihood options. These studies are often rooted in the "New Economics of Labor Migration" approach (de Sherbinin et al., 2022; Hunter & Simon, 2023; Piguet, 2022).

Others identify environmental risks as "push" factors for migration (Bardsley & Hugo, 2010; Lee, 1966) against "pull" factors in destination areas (Williams & Gray, 2020) or as part of an economic cost–benefit analysis (Cameron, 2018; Roback, 1998). Still, others are focused on the resource scarcity hypothesis by which households are compelled to migrate due to the scarification of resources, leaving little alternative coping mechanisms. While the resource scarcity narrative has been criticized for being too simplistic and deterministic (Millock, 2015; Piguet, 2013), new debates have considered "critical thresholds" at which out-migration becomes more likely for individuals, households, and communities (McLeman, 2018). Scholars exploring these thresholds also consider the concept of habitability, which is understood as the outcome of a complex process including socio-cultural dimensions at different scales, as well as local and individual perceptions, for a given place (see, e.g., the HABITABLE Project, n.d.).

Despite an increasing number of studies, the empirical literature attempting to quantify the relationship between environmental events and migration is inconclusive (Cattaneo et al., 2019). Effects are found to be weak or diverge in terms of the direction of effects, and results are dependent on the shocks considered as well as on individual household attributes and contextual factors. For example, climate shocks were found to be positively related to international out-migration in some areas (Coniglio & Pesce, 2015; Gray & Mueller, 2012) but negatively related in others during certain seasons (Nawrotzki & Bakhtsiyarava, 2017). And while some studies report a positive impact of droughts on rural to urban migration (Nawrotzki et al., 2017), others find no significant effect (Mueller et al., 2020). The existing empirical evidence suggests distinct mobility patterns depending on the socioeconomic status of affected households with middle and higher wealth groups showing a stronger migration response to shocks (Bazzi, 2017; Kubik & Maurel, 2016).

Case studies on household shocks and migration in Eastern Africa specifically have considered that the relationship between household shocks and migration varies by the number of shock experienced and the gender of the migrant, as shown in Malawi (Anglewicz & Myroniuk, 2018) and Tanzania (Hirvonen, 2016). Household characteristics also matter, for example in Tanzania, temperature-induced income shocks inhibit long-term migration among men with financial constraints (Hirvonen, 2016) and households of lower wealth groups (Kubik, 2017). The timing of the shock with respect to cropping seasons is also important, as shown in Mozambique (Baez et al., 2020).

Our paper adds to the quantitative literature on the effects of shocks on migration in developing countries by considering a broad time window and accounting for the interplay between different shock types. The TZNPS panel has previously been used in various quantitative studies, for example to study educational and health outcomes of children (Kafle & Jolliffe, 2015; Kafle et al., 2018), price shocks and food security (Rudolf, 2019), informal work (Danquah et al., 2019), land ownership (Lasway & Selejio, 2021), energy choices (Choumert-Nkolo et al., 2019), and environment- or climate-related migration (Chegere & Mrosso, 2022; Hirvonen & Lilleør, 2015; Kubik & Maurel, 2016; Kubik, 2017; Ocello et al., 2015).

Data and methods

Agricultural livelihoods and migration in Tanzania

The literature on climate change impacts, demographic trends, and factors influencing migration in the United Republic of Tanzania is summarized in an assessment by Blocher et al. (2021). The review concludes that due to the high dependence on smallholder farming in the country, climate change-related temperature rise and rainfall variability, plus the general dearth of risk management in many subsistence-based agricultural communities, will add pressure to existing migration drivers. High population growth, increasing population density, and the prevalence of unplanned settlements will likely mean many more people will be exposed to hazards in the future in both rural and urban settings (Centre for Research on the Epidemiology of Disasters (CRED), 2019). Some key trends in the country relevant to livelihoods and migration are summarized in Figs. 1A–D.

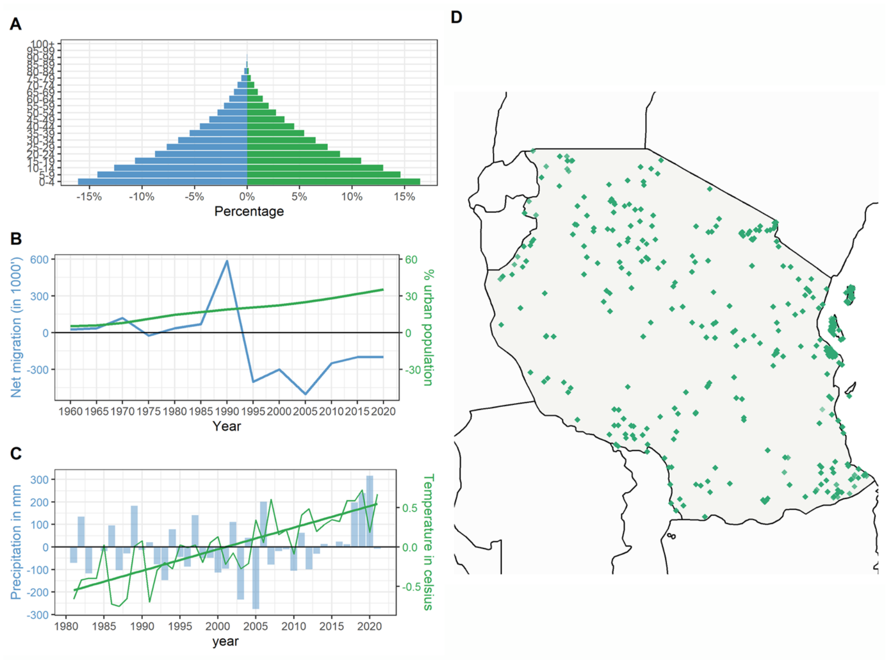

Fig. 1 Background information on Tanzania. **A** The population pyramid projected up to 2020. **B** The net 5-year migration rate in blue (primary *y*-axis) and the share of the population living in urban areas in green (secondary *y*-axis) over the time period 1960–2020. **C** The annual mean surface temperature and rainfall anomalies from 1981 to 2020, averaged over Tanzania during that period, with annual rainfall anomalies in millimeter represented in blue (primary *y*-axis) and temperature anomalies in Celsius in green (secondary *y*-axis). Rainfall of 1 mm/day by rain gauge is roughly equivalent to 1 m^2 of horizontal surface area; 1 mm of rainfall will produce 1 L of water. The data points shown here represent yearly aggregate mean. **D** The map of Tanzania with green points indicating the location of main urban centers and agglomerations. Data: **A**, **B** The World Bank Group, 2022; **C** temperature from ERA5 and rainfall from *CHIRPS: Rainfall Estimates from Rain Gauge and Satellite Observations*, n.d.); **D** TZNPS.

The country currently has a population of nearly 65 million people and is classified as lower-middle income (World Bank Group, 2020). High fertility coupled with an overall low life expectancy contribute to a broad population base with more than half of the population being of working age (15–64 years old) (Fig. 1A). While the country has a developing mixed economy, the agriculture sector still employs the majority (65.7%) of the Tanzanian population (The World Bank Group, 2019).

A growing—but still minority—share of the population lives in urban areas, at roughly 34% of the total (Fig. 1B). While Dar es Salaam has steadily maintained roughly one third of the urban population in the country over at least four decades (Christiaensen et al., 2018; Moshi et al., 2018; Ørtenblad et al., 2019), other agglomerations are developing faster than major cities (United Republic of Tanzania (URT), 2015), in part because these settlements are more accessible to rural migrants (Blocher et al., 2021). Rural-to-rural migration outweighs rural-to-urban migration in the country, and internal migration far outweighs migration of Tanzanians abroad (Blocher et al., 2021).

The Tanzania National Panel Survey

This study uses data derived from the Tanzania National Panel Survey (TZNPS), a nationally representative household survey implemented between 2008 and 2015 by the Tanzania National Bureau of Statistics with support from the World Bank Living Standards Measurement Survey (LSMS-ISA) program. The original sample of 3265 households is clustered in 409 enumeration areas across mainland Tanzania and Zanzibar, of which 2063 households are rural and 1202 are urban. Due to its longitudinal panel structure, the TZNPS allows us to study changes in household characteristics and behaviors over time. The data contain rich information about social and demographic characteristics of households and their members, including on livelihood strategies, poverty dynamics, and challenges faced. The questionnaires also have a detailed module on the households' exposure to a range of environmental and non-environmental shocks and coping and adaptation responses. Importantly, local and distant tracking of migrant and split-off members allow for an unusually low individual attrition rate of 4.84% for all three survey waves. The strength of the panel means that our sample includes households with migrant experiences over time, while in many other panels, individuals dropping out of the sample are likely to include migrants.

In our analysis, we focus on the 16,709 individuals from the originally sampled 3265 households (TZNPS 2008/2009) that were revisited and interviewed in two subsequent waves (TZNPS 2010/2011 and TZNPS 2012/13) and for which we have complete data necessary for our analysis. Substantial data preprocessing was required to track migrant individuals across the three rounds (see Supplementary Materials Section B). More recent rounds of the survey (R4, 2014/2015) are not used in this study, as the sample did not correspond to that used in the first three rounds and individuals could therefore not be tracked across time, which is one main contribution of our longitudinal analysis.

Measurement

To measure migration, we rely on information about household members who were absent for more than three cumulative months in the past 12 months at the time of each survey wave (36 months of migration histories). We calculate a binary (dummy) variable at the household level indicating whether a member was absent. As robustness tests, we also consider a continuous variable representing the share of absent members (ranging 0–100) as additional migration indicator. Over all survey periods, 34.5% of all urban households had at least one member who migrated in the past 12 months and 14.6% of household members absent, on average. Among rural households, migration was less common, with only 27.3% of households having had at least one absent household member and 8.4% of household members absent, on average. Table 1 summarizes these

Table 1 Descriptive statistics of household sample by rural vs. urban

		Rural		Urban	
	Range	Mean	SD	Mean	SD
Migration					
Any migrant in household	0/1	0.273	0.445	0.345	0.475
% of household members that migrated	0–1	0.084	0.180	0.146	0.261
Lifetime migrant in household	0/1	0.511	0.500	0.802	0.398
Household characteristics					
Household size (# of persons)	-	5.718	3.108	4.971	2.726
Household lives in remote area	0/1	0.543	0.498	0.168	0.374
% women in household	0–1	0.518	0.209	0.522	0.239
Any dependent persons in the households	0/1	0.902	0.297	0.793	0.406
Average age of household members (years)	-	25.918	14.020	25.305	10.317
Wealth					
Household is poor	0/1	0.334	0.472	0.068	0.252
Household has access to non-agricultural income	0/1	0.225	0.417	0.742	0.437
Household has earth floor	0/1	0.736	0.441	0.207	0.405
Household has no enhanced walls	0/1	0.436	0.496	0.133	0.339
Household has no enhanced roof	0/1	0.442	0.497	0.076	0.265
Livelihood					
Primary occupation in household is agricultural	0/1	0.686	0.464	0.155	0.362
Income source: food crops	0/1	0.499	0.500	0.112	0.315
Income source: livestock	0/1	0.031	0.174	0.011	0.106
Income source: cash crops	0/1	0.112	0.316	0.024	0.153
Income source: business returns	0/1	0.129	0.335	0.373	0.484
Income source: wage labor	0/1	0.140	0.347	0.382	0.486
Income source: remittances	0/1	0.046	0.210	0.058	0.233
Income source: other	0/1	0.043	0.202	0.039	0.193

Descriptive statistics of household sample (all survey waves) divided by rural versus urban. 0/1 in "range" indicates binary (dummy) variable, 0–1 indicates a share (0–100%). Household members of all ages are included in averages; dependents are considered those under the age of 15 and over the age of 64; all others are considered working age.

numbers and other descriptive statistics for the households in our sample for all three survey waves. Here, we distinguish by urban and rural households due to the significant livelihood and wealth differences that are also relevant for our analysis.

To measure household exposure to different types of shocks, we rely on a special shock module in the TZNPS questionnaire. In this module, household heads or the most knowledgeable household member were asked to consider a list of 18 defined adverse events—plus a category for "other"—and report whether the household was negatively affected by them over the past 5 years. The defined events include a range of different types of shocks, including drought or flood events, crop disease or crop pests, loss of salaried employment or non-payment of salary, business failure, or health-related events. In addition, households ranked up to three most significant shocks experienced and reported whether these caused a reduction in household "income" and/or "assets," both, or neither. The households also reported the month and year of the ranked shocks as well as their primary household responses to them, choosing up to three out of a list of 18 possible options (see Table 2, this section, and Fig. 4, in the "Data and methods" section).

As information about the timing/seasonality of shocks is needed for our analysis and only available for the ranked shocks, we focus on the most severe shocks in the construction of our shock measures. For our indicators, we construct lagged variables that capture how many shocks have occurred in the 12 (time t), 13–24 ($t-1$), 25–36 ($t-2$), 37–48 ($t-3$), and 49–60 ($t-4$) months prior to the interview dates. As an additional measure, we calculate the total number of shocks experienced by a household within the last 24 months (near time horizon) and 25–48 months (distant time horizon) (Supplementary Table S4).

Adapting the classification approach developed by Hoddinott and Quisumbing (Hoddinott et al., 2003) and further employed by Dercon, Hoddinott, and Woldehanna (Dercon et al., 2005), we divide the shocks into categories: agricultural, climatic, market economic, health, socio-political, and other. We consider the first two categories as directly environment-related and the latter as non-environmental. Table 2 shows this categorization, and Supplementary Section A provides further details. As we know, some shocks are correlated across categories—for example, floods are related to food prices—we conduct a number of robustness checks to ensure that our broad categorization is not driving the results. We also conduct a

Table 2 Measurement details and categorization of reported shocks

Environmental	Non-environmental
Drought or floods (101), crop disease or crop pests (102), livestock died or were stolen (103), large fall in sale prices for crops (106), large rise in agricultural input prices (108), severe water shortage (109)	Household business failure, non-agricultural (104), loss of salaried employment or non-payment of salary (105), large rise in price of food (107), loss of land (110), chronic/severe illness or accident of household member (111), death of a member of household (112), death of other family member (113), breakup of the household (114), jailed (115), fire (116), hijacking/robbery/burglary/assault (117), dwelling damaged, destroyed (118), other not specified (119)

TZNPS codes are provided in parentheses

separate analysis where we control for the co-occurrence of different shocks and their related impacts on migration (Supplementary Table S4).

The derived shock measures are based on the household's own experiences and subjective perceptions. This subjectivity in the measurement comes with certain challenges, such as a loss in comparability and objectivity of the derived variables. However, our approach is in line with a growing stream of climate migration research that emphasizes the actual experience of households and their perceptions of environmental conditions as main determinant of migration decisions (De Longueville et al., 2020; Parsons & Nielsen, 2020; Zander et al., 2013). Households may misperceive the severity and frequency of shocks or may face challenges with recalling certain events. However, we do not expect this to lead to systematic biases in our longitudinal estimation as such recall issues would only affect the shock measurement, but not the measurement of the migration outcome over time. Hence, even though the estimation may become noisier, the estimated relationships are expected to be valid.

In addition to the main outcome and explanatory variables, we derive a number of further indicators from the data. Self-reported dwelling characteristics and living conditions informed the construction of wealth categories for all households (Supplementary Materials Table S2), adapted from the Demographic and Health Survey Wealth Index (Rutstein, 2014; Rutstein & Johnson, 2004). In addition, we construct a dummy variable measuring whether a household lives in a rural or urban area and whether it is dependent on agriculture, i.e., at least one household member works in agriculture. Furthermore, to obtain information about the profile of migrants, we derive different socioeconomic characteristics about absent household members from the household roster.

Estimation approach

To estimate the relationship between different types of shock events and migration outcomes, we combine the migration and shock data at the household level and employ a fixed effects panel model of the following form:

$$M_{\mathrm{it}} = \sum_{k=0}^{4} \beta_{\mathrm{k}} S_{\mathrm{it-k}} + \alpha_{\mathrm{i}} + \theta_{\mathrm{m}} + \mu_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \quad (1)$$

where M_{it} captures whether any household member was absent in the 12 months prior to the survey. $S_{\mathrm{it-k}}$ reflects the number of shocks that occurred 12 (t), 13–24 ($t-1$), 25–36 ($t-2$), 37–48 ($t-3$), and 49–60 ($t-4$) months prior to the survey (t). Our baseline models (Fig. 5) are estimated in a parsimonious way, focusing primarily on the estimation of the relationships of main interest. All models include a household-specific intercept α_{i} (household fixed effect) to control for time-invariant factors (unobserved heterogeneity) that may confound the estimation, such as stable characteristics of the household or structural influences of the community. In addition, we include season/month fixed effects θ_{m} and year fixed effects μ_{t} to control for time trends and seasonal changes that are common across all regions.

In additional interaction models (Table 3), we test whether impacts of shocks affect households differently. Here, we interact our aggregate shock variable, measuring the number of times a household was affected by any type of shock in the past 12 months with different socioeconomic household characteristics. These capture whether (1) the household is located in a rural or urban area, (2) whether it is located in proximity to an urban center, (3) whether at least one household member has an agricultural occupation, (4) whether at least one household member has an alternative occupation outside of agriculture, (5) whether the household falls under the poverty line, (6) whether any household member was born outside the current location of residence, and (7) whether any children (< 16 years of age) or older individuals (65 > years of age) live in the household. The interaction models take the following form:

$$M_{\mathrm{it}} = \beta_0(S_{\mathrm{it}} + S_{\mathrm{it-1}}) \times I_{\mathrm{i}} + \sum_{k=2}^{4} \beta_{\mathrm{k}} S_{\mathrm{it-k}} + \alpha_{\mathrm{i}} + \theta_{\mathrm{m}} + \mu_{\mathrm{t}} + \varepsilon_{\mathrm{it}} \tag{2}$$

where $S_{\mathrm{it}} + S_{\mathrm{it-1}}$ reflect the aggregate number of shocks that occurred 24 months prior to the survey (t), and I_{i} is the value of the binary coded interaction variables. Here, we decided to consider the number of shocks in the past 12 and 13 to 24 months together, as these were most strongly correlated with the migration outcome. For the estimation of the interactions, we focus on the values of the interaction variables in the first wave of the TZNPS to mitigate the risks that these variables may have themselves been affected by the different types of shocks. Hence, all interaction variables reflect baseline values which are kept constant over time allowing us to distinguish the effects of shocks on different types of households. Because the interaction variables do not vary over time, no main effects are reported for these variables in the fixed effects estimation.

In additional robustness tests, we included further time-varying demographic covariates into our model, considering household characteristics: size, mean age, rural versus urban location, share of women, and share of dependents (Supplementary Tables S5 and S6). As these variables may themselves be affected by the shocks, we refrained from including them into our main specifications. Furthermore, we estimated a series of extended models using ordinary least squares (OLS) estimation to understand differential risks between households of being affected by a shock and becoming mobile.

Limitations

Our study faces different limitations which are important for the interpretation of the results. First, we focus on absenteeism as primary migration outcome. While with this we intend to capture short-term mobility, we omit movements that are more permanent. In particular, the TZNPS did not track cases of whole households migrating. Households may leave the panel when they move to a new location, despite advanced tracking and low attrition, as in the case of TZNPS. This means that we may lose a few potentially relevant cases of households. Such challenges are common to research on environmental change

Table 3 Linear fixed effects models: exploring heterogeneities in migration responses by household characteristics

	Outcome variable: household member absent (0/1)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Impacts of any shocks in past 24 m							
Urban household	0.00072						
	[0.003]						
Rural household	0.00467**						
	[0.002]						
Household without remote location		0.00241					
		[0.002]					
Household with remote location		0.00419*					
		[0.002]					
Non-agricultural occupation			0.0002				
			[0.002]				
Agricultural occupation			0.00621**				
			[0.003]				
No alternative income available				0.00532*			
				[0.003]			
Alternative income available				0.00022			
				[0.002]			
Non-poor household					0.00231		
					[0.002]		
Poor household					0.00548*		
					[0.003]		
No lifetime migrant in household						0.00102	
						[0.002]	

Table 3 (continued)

	Outcome variable: household member absent (0/1)						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Lifetime migrant in household						0.00478*	
						[0.002]	
No children/seniors in household							0.00029
							[0.003]
Children/seniors in household							0.00369
							[0.002]
Model controls for							
Household fixed effects	X	X	X	X	X	X	X
Year fixed effects	X	X	X	X	X	X	X
Season/months fixed effects	X	X	X	X	X	X	X
Shocks occurring in previous periods	X	X	X	X	X	X	X
Observations	8980	8980	8980	8980	8980	8980	8980
AIC	6053.252	6054.38	6050.453	6051.754	6054.091	6052.051	6053.382
R^2 (within)	0.04863	0.04851	0.04892	0.04879	0.04854	0.04875	0.04861
R^2 (between)	0.06559	0.06761	0.06355	0.06416	0.06611	0.06998	0.06726

Coefficients displayed in cells with cluster robust standard errors in brackets. Standard errors are clustered at the village or community level ($k=99$ clusters). All models control for household, year, and season fixed effects as well as for the occurrence of shocks in previous periods (25–36 m, 37–48 m, 49–60 m). All interaction variables were measured in wave 1 of the survey and kept constant throughout all survey waves. Dependent household members are considered as children under 16 years or adults over 65 years of age (seniors)

p-values: * < 0.1; ** < 0.05; *** < 0.01

and migration that often relies on indirect and restricted measures of human mobility (Hoffmann et al., 2021). Despite this limitation, we believe our measure to be suitable to test our main hypotheses because internal short-term movements are the most prevalent form of migration in the region (Blocher et al, 2021; Hirvonen, 2016; Kubik, 2017) as well as the form of movement most suited to risk sharing and immediate coping in response to external hazards and disruptive events (De Weerdt & Hirvonen, 2016).

Second, we consider shocks that were self-reported by the households in the surveys as primary explanatory variables. Recall data are necessary due to the impossibility of directly observing the shocks to which households were exposed. Studying self-reported data has disadvantages as they might be prone to recall ability decreasing over time, post-hoc justification, and other reporting biases which can affect the measurement (Heltberg et al., 2015; Nguyen & Nguyen, 2020). In addition, we cannot exactly determine the timing of the mobility in the past 12 months making it difficult to accurately match the occurrence of shocks in the recent past to household responses.

Despite these limitations, the survey-based approach also offers a number of advantages. Unlike analyses that rely only on objective measures, we accurately capture whether a household was exposed and vulnerable to an event reflecting the actual impacts of shocks. Furthermore, by comparing households to themselves over time in our fixed effects estimation, we can account for relatively stable differences in reporting behaviors between households (Hassan, 2006; Moreno-Serra et al., 2022). Controlling for these stable differences, we have no reason to believe that those households whose migration patterns changed over time would have a systematically different recall ability than those households remaining immobile.

Although we use a rigorous longitudinal analytical approach, our estimated coefficients do not represent perfect causal relationships. Migration is multi-causal and can be affected by a range of factors, which can be correlated over time and space. While in our analysis, we attempt to control for the co-occurrence of different shock types and the cascading nature of shocks over time, other correlated events, or processes not captured in our analysis may affect the estimation. Similarly, challenges with the measurement of both shocks and mobility, as discussed above, may affect the accuracy of our analysis. For example, since our analysis is based on the three most severe shocks experienced by the households, this leaves a potential blind spot in the assessment of the full range of shocks encountered. Instead of a causal identification, our analytical approach allows us to show how shocks over time and across different shock types can have very different effects on households and that different subgroups in the population are differently affected. Our analysis adds important insights in the simultaneous estimation of the effects of different shock types, the exploration of temporally evolving processes in the relationships, and the understanding of heterogeneity in mobility responses to disruptive events in different contexts.

Results

Diverse livelihood risks and shocks

Households in Tanzania are exposed to a range of environmental and non-environmental shocks (Fig. 2). Most of the shocks experienced fall into the category of food

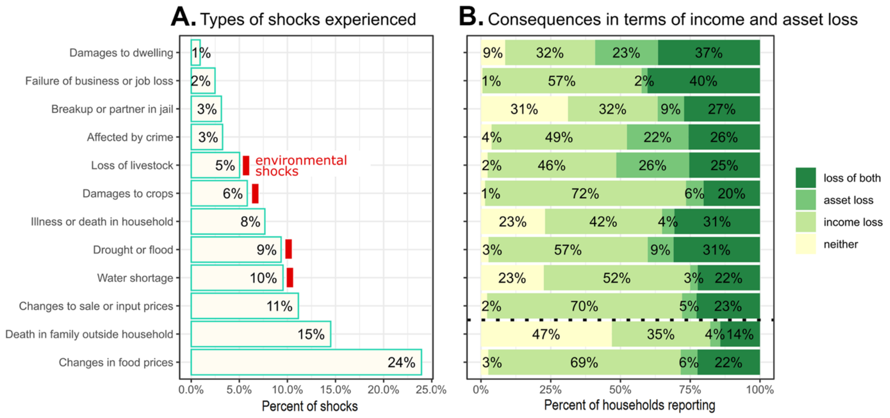

Fig. 2 Types of shocks and their consequences for households. **A** The percentage of different environmental and non-environmental shocks affecting households. **B** The percentage of households reporting different consequences for the household of the different shock. These are distinguished into whether a household lost income, assets, both, or neither due to a shock

price-related (24%) or health disruptions, such as an illness or death in the household (8%) or the death of a family member outside the household (15%). In addition, issues related to water availability (10%), drought or flooding events (9%), damages to crops (6%), and loss of livestock (5%) are commonly reported. For our analysis, we classified the latter shock types as environmental and the remainder as non-environmental.

While most of the experienced shocks had consequences for the affected households, agricultural and food price shocks were most commonly found to lead to an asset or income loss (Fig. 2B). With 63% of the households in the sample residing in a rural area and 49.9% of those relying on food crops, adverse events such as crop pests, livestock mortality, and large price fluctuations represent a significant livelihood risk for these households. Food price shocks (experienced by 24% of households) and damage to crops (experienced by 6%) can be influenced by both environmental and non-environmental factors. We find certain climate-related shocks like water shortages (experienced by 10%) or droughts and floods (experienced by 9%) are not as closely related to income loss. Subsistence-based households may benefit from community risk-sharing for certain shocks. For example, communities in Tanzania traditionally support households facing illness and jointly bear the financial shock represented by funerals (Dercon et al., 2006).

The occurrence of shocks is not independent. Certain shock types are correlated and are thus more likely to co-occur and to affect the same household (Fig. 3A). In particular, drought and flood events are closely related to crop damages, loss of livestock, as well as changes in sale or input prices. Water shortages are linked to changes in food prices, and damages to crops are associated with loss of livestock and changes to sale or input prices. The occurrence of economic shocks often goes hand in hand with disruptive family events or other social shocks.

Shocks are also correlated over time (Fig. 3B). Households that have experienced a shock in the recent past ($t-1$, 13–24 months) have a probability of nearly 50% of

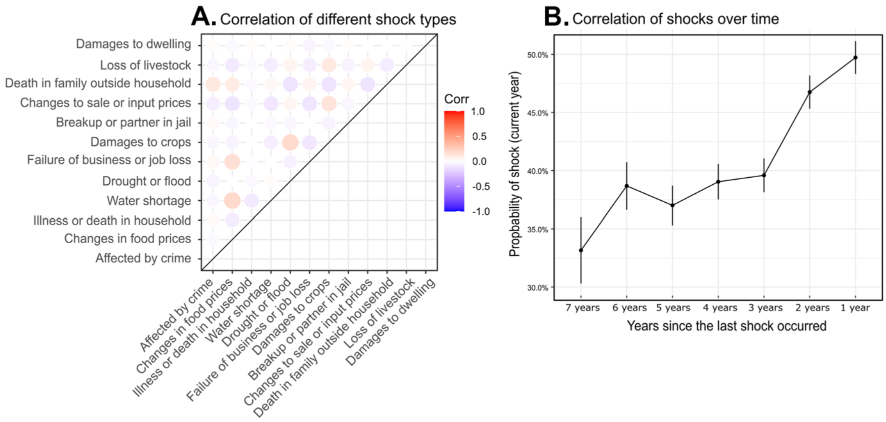

Fig. 3 Correlation of different shock types and correlation of shocks over time. **A** How the occurrence of different types of shocks is related. **B** How the probability of being affected by a shock for a household in time *t* depends on whether the household was affected by another shock in the years prior. Here, we consider shocks that occurred 1 to 7 years prior to *t*, showing how the occurrence of shocks in the recent past increases the probability of being again affected by an event in the present.

experiencing another shock in the current period (t). On the other hand, households who have not experienced a shock in the recent past have a considerably lower probability of being affected by a shock again. For example, if a household was affected by a shock in the past 13–24 months, then the probability of being affected again is almost 7.5% higher compared to a household who was last affected in the period 25 to 36 months ($t-2$) (Fig. 3B). In our empirical analysis, we explicitly model those temporal interdependencies to show how the accumulation of shocks influences migration patterns at the household-level.

Household adaptation and coping

Households use a range of adaptation and coping strategies to deal with environmental and non-environmental hazards. This section presents self-reported responses to shocks and is separate from the statistical relationships between shock experiences and migration responses below. Use of own savings (39.7%), help from relatives or friends (25.2%) and the engagement in spiritual efforts (7.3%) were the most common responses. At the same time, changes in eating patterns were observed in 6% of all cases, which can be a sign of an increased level of vulnerability.

Only 0.8% of all households self-report that a member migrating was among their primary household responses to a shock (Fig. 4A). This self-reported number is likely to underestimate actual migration, as migration is often a longer-term strategy employed by households and may therefore not be perceived by them as a direct response to mitigate a shock. Even if multiple pressures including environmental degradation underlie migration, people will consider proximate causes of movement, like hunger or income loss, as their reason for moving (Hugo, 2008; Suhrke,

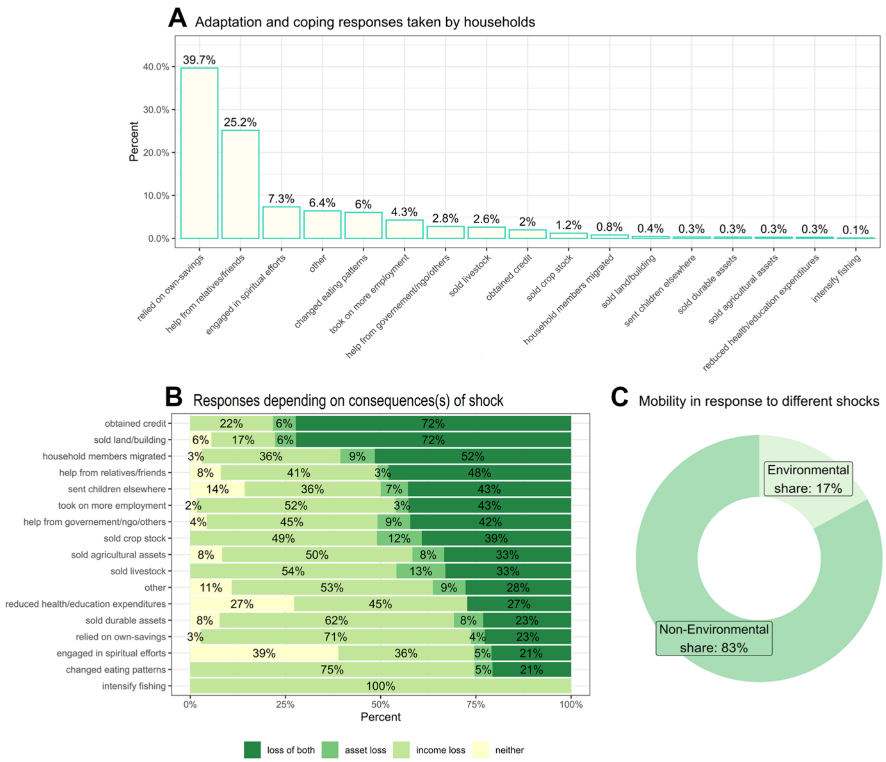

Fig. 4 Adaptation and coping responses undertaken by households. **A** The distribution of adaptation and coping activities in response to a shock reported by households over all survey waves. **B** Responses by the reported consequence(s) of the experienced shock on the household. **C** The use of mobility in response to different shock types. "Migration of a household member" is more commonly reported in response to non-environmental shocks as compared to environmental shocks (per our categorization).

1994). To account for this in our statistical analyses, we consider broadly the relation between the occurrence of shock events and migratory responses over longer time horizons.

Depending on the types of losses encountered by the households, the chosen coping responses differed (Fig. 4B). For example, among the households that reported having taken credit or sold their land or building, 72% in each case had previously encountered a shock that had led to a loss of both income and assets. Likewise, those who reported using migration as a coping and adaptation mechanism were also likely to have experienced income and/or asset loss (97%). Changes in mobility are found to be more common after non-environmental shocks as compared to environmental shocks (Fig. 4C).

The impacts of environmental and non-environmental shocks on migration

We consider whether a family member was absent for more than 3 months in the past 12 months at the time of the survey (current time period t) as primary migration outcome (dummy variable). Our models consider variables reflecting shocks occurring 1–12 (time t), 13–24 ($t-1$), 25–36 ($t-2$), 37–48 ($t-3$), and 49–60 months ($t-4$) prior to the survey enumeration. Figure 5 summarizes the fixed effects regression model estimates for aggregated environmental and non-environmental shocks over time.

The results indicate a significant and meaningful effect of our aggregate measure for environmental shocks on mobility patterns. The probability for having an absent household member increases by 0.81% with each additional environmental shock experienced in the past 12 months prior to the survey (t). Likewise, significant, but weaker effects are observed for shocks occurring in the previous time periods ($t-2$ and $t-3$). For shocks occurring in the period 49–60 months prior to the survey, the effects remain positive but are non-significant. For the aggregated non-environmental shock measure, on the other hand, the observed effects on mobility are inconsistent.

Our results highlight the importance of the wider temporal context and of potential dependencies in the occurrence of shocks over time. In addition to our main models, we performed various sensitivity analyses, where we consider shocks in broader time windows (1–24 and 25–48 months) separately as well as jointly (Supplementary Table S4). We also conducted additional models using the percentage of household members migrating in response to shocks as alternative outcome and controlling for a number of time-varying demographic factors (Supplementary Tables S5 and S6, respectively). All of our main results and conclusions derived remain fully robust to these variations in the model specification and measurement.

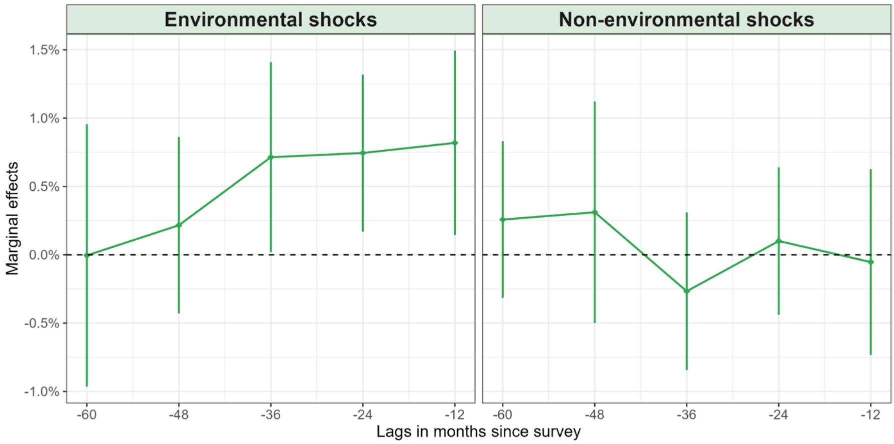

Fig. 5 Effects of environmental and non-environmental shocks on household mobility over time. Left: The marginal effects (y-axis) of lagged (t, $t-1$, $t-2$, $t-3$, $t-4$) environmental shocks (x-axis) on the probability of a household member being absent in the current period. Right:The effects of lagged non-environmental shocks (x-axis). The marginal effects reflect the changes in migration probability with each additional shock experienced by the household in the time window considered. Vertical bars represent 90% confidence intervals

Impacts of different shock types

In extended models, we break up the aggregate impacts of environmental and non-environmental shocks to provide greater detail to our analysis and to understand how specific shocks influence migration. Figure 6 shows a facetted dot-whisker coefficient plot illustrating the findings of a range of fixed effects models regressing the migration outcome on the occurrence of different shock types. Each row in the graph stands for one model estimating the impact of the occurrence of a shock in the same period (t) and in past periods ($t-1$ to $t-4$) on migration.

Impacts on migration are not uniform but strongly differ for different shocks. While some shock types exert a positive impact, others have a clear constraining effect on migration. The coefficients for changes to agricultural sale or input prices, damages to crops, and loss of livestock are positively related with migration up to a lag of 36 months ($t-2$). All of these shocks exert an immediate impact on the mostly agricultural livelihoods of the survey respondents and may therefore be particularly consequential for migration. They are all also correlated with the occurrence of extreme weather events, such as drought and flooding (Fig. 3A), and may represent relevant impact channels through which environmental change processes affect local livelihoods and migration decisions. Likewise, experiencing a breakup of the household or having a household member in jail has a major impact on migration, but only for the current period (t). Encountering damages to a dwelling also exerts a positive effect on migration, but with wide confidence intervals due to the rare occurrence of these events.

On the other hand, having been affected by a crime, drought and flooding events, and a health problem within the household are all found to reduce migration, at least

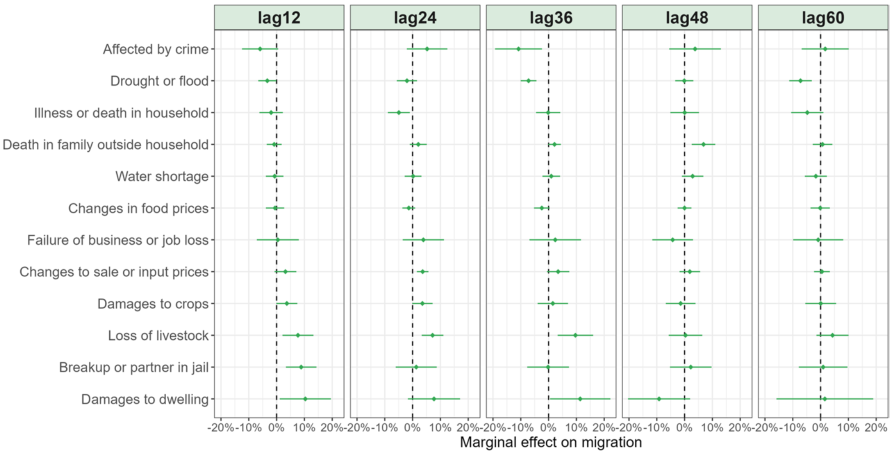

Fig. 6 Coefficient plot showing migration impacts by individual shock types for current period t (lag12) and previous periods (lag24 to lag60). Each row in the plot represents a separate model testing for the impact of one shock category on migration. The marginal effects reflect the changes in migration probability with each additional shock experienced by the household. Whiskers represent 90% confidence intervals

in the short term. Interestingly, we observe the constraining effects to be particularly strong for shocks that have occurred recently (up to lag of 24 months; $t-1$) as compared to shocks occurring longer ago. These findings illustrate the differential impacts of different types of shocks on household mobility and further highlight the importance of analyzing shocks over a broader time window and with granularity.

Differential migration impacts by household characteristics

To further refine our analysis, Table 3 presents differences in migration impacts conditional on stable characteristics of the households, which were measured in the first survey wave. As both selected environmental and non-environmental shocks were found to be related to changes in migration patterns, we consider here the total number of shocks affecting households in a given period as our main explanatory variable (continuous). We use interaction models, focusing on the differential effects of shocks occurring in the recent past (up to a lag of 24 months), which were found to be overall the most influential for mobility. While we focus here on shocks that have occurred in the period 1–24 months prior to the survey, all models control for the occurrence of shocks in the previous periods to account for temporal interdependencies.

In our interaction models, we consider interactions by whether a household was located in a rural or urban area in the first wave (model 1); was located in a remote area without access to public infrastructure, meaning the distance from the household to the next urban center was >20 km and the distance to the next major street was >10 km (model 2); depended primarily on an agricultural occupation (model 3); had alternative non-agricultural income sources available (model 4); were poor based on a standardized wealth index (model 4); had a household member who was born in a different district than where the household resided at the time of the first enumeration (referred to as a "lifetime" migrant in the survey) (model 5); and had more than two dependent household members (i.e., children under 16 years or adults over 65 years of age).

We find that migration behavior depends substantially on livelihood context. Migration responses to shocks are larger among rural households, households living in remote areas, and households with a primarily agricultural occupation. For example, for households with an agricultural occupation, each additional shock in the past 24 months increased the probability of a household member being absent by 0.62% (SE 0.3), while we do not see corresponding effects for non-agricultural households.

Economic factors prove to be important as well. We find households that do not have access to alternative, non-agricultural income to respond most strongly to shocks. Their migration probability increases by 0.53% on average (SE 0.3) with every additional shock experienced. At the same time, poorer households show a greater tendency to migrate if they are affected by shocks. On average, their migration probability increases by 0.55% (SE 0.3) with every additional shock to which they are exposed. These findings highlight that it is often the least advantaged who are most severely affected by the impacts of both environmental and non-environmental shocks, resulting in increased migration pressures.

Among the demographic factors, we find that households with a so-called "lifetime" migrant showed a higher migration tendency in response to shocks with an estimated relationship coefficient of 0.48% (SE 0.2). Likewise, households with multiple dependents (i.e., children or elderly) seem to be more likely to become mobile after a shock, but these effects are not statistically significant. Overall, the results indicate multilayered interactions with local socioeconomic conditions. They show, in particular, that shocks influence the migration behavior of agriculturally dependent households in rural areas. It is in particular those households who live in remote areas, do not have alternative income sources, and are poorer that show the strongest migration responses.

Vulnerability and migrant household composition in Tanzania

In a final step, we explore in greater detail the factors that are related to the exposure to shocks and migration in the current period (*t*). Unlike our other dynamic analyses, we here rely on pooled ordinary least squares (OLS) models to explore how relatively stable background characteristics of households are related to the exposure to shocks and the probability of having a household member absent (Table 4). Taken together with our summary statistics (Table 1) which demonstrate that urban households are more likely than rural households to have wage labor and business income sources as well as higher wealth levels (represented by improved flooring, walling, or roofing; see supplementary Table S2), these additional analyses allow us to form a picture of vulnerability profiles in our sample.

Overall, rural households and those dependent on an agricultural income are more likely to report being affected by environmental shocks and less likely to report being affected by non-environmental shocks. Rural and agriculturally dependent households as well as poorer households in all locations are also overall less likely to have a migrant household member. These findings are consistent with previous research in the region finding that rural and remote households are more highly exposed to climate change impacts and co-stressors (Blocher et al., 2021).

Considering household composition, we see that larger households have a higher probability of having a migrant. A high dependency ratio in the household—meaning a high number of elderly and children dependents compared to working-age household members—increases the risk of being affected by an environmental shock and the probability of having a migrant household member. The presence of a "lifetime" migrant in the household increases the probability of having a migrant household member (absent). This is consistent with research on the social determinants of migration demonstrating that migrant networks and the presence within the household of a family member with prior migrant experience are key factors in lowering migration costs and influencing migration probabilities (Massey & España, 1987).

Table 4 Determinants of exposure and migration

	Household experienced any environmental shock (1)	**Household experienced any non-environmental shock** (2)	**Household has a migrant household member** (3)
Rural location	0.300***	−0.378***	−0.201***
	[0.107]	[0.066]	[0.077]
Wealth category	0.113**	0.023	−0.140*
	[0.054]	[0.056]	[0.083]
Agricultural household	0.218***	−0.050**	−0.018
	[0.034]	[0.022]	[0.029]
Household size	−0.023**	−0.003	0.153***
	[0.011]	[0.014]	[0.013]
% women in household	−0.167*	0.162	0.153
	[0.089]	[0.108]	[0.095]
% dependents in household	0.358***	−0.006	−1.532***
	[0.119]	[0.097]	[0.150]
"Lifetime" migrant present	0.071	0.033	0.370***
	[0.051]	[0.059]	[0.067]
Distance to next urban center	0.004***	-0.000	0.003***
	[0.001]	[0.001]	[0.001]
Observations	8704	8704	8704
AIC	11.464.618	11.649.095	10.053.066

Marginal effects; standard errors in brackets (d) for discrete change of dummy variable from 0 to 1

$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Discussion and conclusion

This study considers how different types of environmental and non-environmental shocks influence migration while placing a special emphasis on the embeddedness of household responses in a wider temporal context, and on the dependence of responses on various household characteristics. A number of key findings are worth noting.

First, we demonstrate that shocks are not occurring in isolation but are interdependent and correlated over time. These interlinkages are important as they influence the estimation of migration impacts. Considering that our results indicate certain shock types are more likely to co-occur and to affect the same household (Fig. 3A), some households are likely to face compounded or re-occurring effects of shocks that can significantly affect household resources.

Second, we find consistent, positive effects of our aggregate environmental shock measure on migration over time. We find a particularly strong effect of environmental shocks on migration in the current time period t (1–12 months prior to survey), namely that the probability of having an absent household member increases with each additional environmental shock experienced. Significant, but weaker effects are observed for shocks occurring in the previous time periods

(13–48 months prior) and the picture remains consistent but insignificant for $t-4$ (48–60 months prior). For our aggregated non-environmental shock measure, on the other hand, the observed effects on mobility are inconsistent. Our shock categorization allows us to better understand the clearer influence of environmental shocks driving out-migration when disentangled from other types of shocks.

Third, when we break down the impact of different shocks, we find some shock types exert a consistent positive impact on migration, while others have a clear constraining effect. This is consistent with other studies showing that the types of adverse household shocks matter to migration responses (Anglewicz & Myroniuk, 2018; Damon & Wisniewski, 2015; Nikoloski et al., 2017). Moreover, we find a consistent positive or negative effect on migration of certain shocks, in line with other studies. Loss of livestock, for example, has been found in other context to be positively related to out-migration in developing countries (Behnke et al., 2011; Halliday, 2006; Mendola, 2012). Health shocks have previously been identified as important factors in raising vulnerability and potentially constraining mobility patterns (Ludolph & Sedova, 2021; McMichael et al., 2012). We find the constraining effects to be particularly strong for shocks that have occurred recently (up to lag of 24 months) as compared to shocks occurring longer ago; this is in line with other studies considering only one time period for shocks, and which interpreted the results as support for the resource scarcity hypothesis (Mueller et al., 2020; Nawrotzki & DeWaard, 2018) or "immobile" or "trapped" population narrative (Adams, 2016; Black & Collyer, 2014; Nawrotzki & DeWaard, 2018).

Not accounting for whether the household had experienced an environmental or non-environmental shock in previous periods can potentially lead to overlooking relevant migration impacts of shocks. Our research begins to address the common challenge for migration data that timing of migration cannot typically be matched to the timing of environmental stimuli.

There are different explanations for why impacts of shocks only become apparent over longer time horizons. A first interpretation is that households require time and effort to prepare a household response, including migration. Migration is a socially and financially expensive endeavor, and many households do not readily have the resources. A second possibility is that exposure to shocks may erode household resources in the immediate aftermath, delaying household adaptation and coping responses. These first two interpretations help explain our finding that most households do not report having used migration as an immediate response to a shock and are in line with the resource scarcity hypothesis commonly referred to in scholarly and public debates (Burrows & Kinney, 2016; Homer-Dixon, 1999; Van der Gheest, 2011). A third interpretation is that the detrimental effects of shocks may snowball or only become apparent over time. While households may perceive that they cope with a disruptive event in the short term, more substantive adjustments might be required over a longer time horizon. For example, households may be forced to sell assets, reducing the resource base of the household in the longer term (Dercon et al., 2005). Migration may be preferred as a possible new source of income via remittances while reducing pressure on household resources (Gemenne & Blocher, 2017). Households may perceive certain shocks as more severe over the longer term and raise their willingness to invest in risky migration strategies.

Finally, we distinguish by different types of households and specific categories of shocks and show that migration outcomes can largely differ depending on the respective circumstances and contexts, with some shock types increasing and others reducing mobility. Given that households' investment in migration as a risk-spreading measure is related to their perceptions of the challenges facing them, different types and combinations of shocks are likely related to divergent levels of investment in migration, affecting the distance and duration of migration used. Williams and Gray (2020) use the ready-willing-and-able perspective to make sense of non-linear migration patterns, suggesting that different types of weather shocks may not lead to absolute changes in migration flows but rather that some households may modify the type of migration employed—often resulting in more short-term movements. Levels of willingness to migrate are also related to household aspirations and capabilities, which are likely eroded over time if multiple or repeated shocks occur (Zickgraf, 2018).

Importantly, we find that migration patterns differ between different groups, namely, between rural and urban households as well as between poor and wealthier households. This finding highlights the importance of looking at groups with different resources and capacities in migration research. It is likely that highly agriculturally dependent and poor households have limited social safety nets and few options to diversify income sources in place if a shock occurs (Bryan et al., 2009; Panda 2013). Instead, they may be forced to search for alternative means of income outside their home communities. This may be especially true for covariate shocks because community-level support is less available. Other research suggests migration of poorer households may be constrained by resource scarcity and liquidity constraints (Ayeb-Karlsson, 2020; Zickgraf, 2018). However, households may appear to be trapped in place in the immediate aftermath but include migration as part of responses later.

Overall, our findings complement the existing body of literature by presenting novel evidence on the mobility impacts of shocks, distinguishing aggregate impacts, as well as impacts broken by different shock categories and household types. Our conclusions support the body of literature on migration as a risk-spreading or risk-reducing strategy and highlight the need for a consideration of temporal aspects, different household types, and different environmental and non-environmental shocks. Populations' risk-adverseness when it comes to migration may change over time, and out-migration may become a more common response when shocks accumulate, consistent with the "critical thresholds/ tipping points" narrative (Horton et al., 2021; McLeman et al., 2021). Our findings have important implications for the concept of habitability, namely that as environmental problems become worse or compounded, migration may become—or become perceived as—an increasingly necessary option.

Future research could build in various ways on our results. One would be to chart how previous shocks enhance the negative impact of subsequent shocks, building on our consideration of how different shock types are linked. Such research could consider qualitative evidence to provide context and add nuance. Future longitudinal research could expand on the relationship between shocks and migration over time. We consider broadly the relation between the occurrence of shock events and migratory responses over longer time horizons, an approach that can be further explored by other research with greater specificity in time-lagged shocks. Finally, our study also has important methodological implications that can be integrated into future research, namely that high-quality longitudinal data are important. These allow for a more granular analysis of shock events and inter-dependencies over time.

This study also has important policy implications given the current dire projections for the impact of climate change in developing countries and particularly in some areas of Sub-Saharan Africa. An increase in the frequency and intensity of environmental shocks in Africa are very likely under some emissions scenarios (see higher-end representative concentration pathway (RCPs) in IPCC, 2013). Our research suggests that areas dominated by poor or agriculturally-dependent communities are likely to witness a change to the number and temporal nature of internal migrants. Moreover, when and why a place is no longer perceived as habitable and migration becomes a more common coping strategy has important implications for UNFCCC discussions, especially those on loss and damage.

For countries already facing significant challenges to inclusive, sustainable development, there is a strong need for policy solutions that can holistically address these seemingly intractable issues. Given that different households may respond to shocks differently, there are no one-size-fits-all policies. In addition to strengthening local adaptation efforts, it is important to advance policy initiatives at the international level to protect and support migrants and displaced persons in the context of climate change. Previous achievements in this direction include the objectives 2 and 5 of the 2018 Global Compact on Migration (Kälin, 2019; McLeman, 2019), the 2015 Nansen Initiative Protection Agenda, and subsequent work of the Platform on Disaster Displacement (PDD) (McLeman & Gemenne, 2018); and UNFCCC discussions (Warner, 2012, 2022).

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by JB and RH. Figures were produced by RH. The first draft of the manuscript was written by JB and RH, and all authors commented on previous versions of the manuscript. Peer review comments were discussed among all authors, and revisions were led by JB and RH. All authors read and approved the final manuscript.

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Data availability The dataset used for this study is based on the data from the World Bank Living Standards Measurement Study—Integrated Surveys on Agriculture (LSMS-ISA), available from the World Bank data catalog https://microdata.worldbank.org/index.php/catalog/lsms/.

Declarations

Competing interests The authors declare no competing interests.

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